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OPTIMISATION OF WELDING PROCESS OF COMPOSITE CHROMIUM-CARBIDE BASED TUBULAR ELECTRODE FOR HARDFACING

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ABSTRACT

The objective of this research work was to investigate the effect of tubular electrode parameters such as baking temperature of electrode (300, 350 and 400°C), duration of baking of electrode (2, 2.5 and 3 hr) and wt. % of chromium (20, 25 and 30 wt. %) on hardfaced surface. The hardfaced surface is obtained using welding process. Specimens so prepared are tested for hardness, with Rockwell hardness tester. Taguchi method is applied for predicting the optimum process parameters which maximize the hardness of hardfaced surface using composite tubular electrode. The result showed that the optimum level of process parameters to obtain good mechanical properties for the hard faced surface are 30% volume fraction of chromium, 300°C of baking and 2.5 hr of baking electrode for maximum hardness. From the analysis it was evident that the volume fraction of chromium is a major contributing factor (52.6%) for improving hardness.

KEYWORDS: Tubular Electrode, Welding, Hardness, Taguchi, Hardfacing

INTRODUCTION

The most engineering components at some stage suffer from the varying effects of wear; it is one of the main causes of expensive material losses and cost-intensive break downs of machines and equipment. Although the process of wear is unavoidable, it can be reduced. The methods employed for the reduction of wear fall into two categories: surface treatments and coating processes [1]. Hard facing is a low-cost method of depositing wear-resistant surfaces on metal components which are exposed to high abrasion environment to extend their service life [2]. For hard facing composite tubular electrode is used, which is a basically coated, alloyed electrode which deposits complex chromium carbides in an iron rich ferrite matrix. It is resistant to both abrasion (coarse and fine) and impact loading (moderate to heavy) [3]. Tubular electrodes are filled with metal powders (carbides of Cr and Nb) with base alloy powders. This electrode produces a deposit characterised by an exceptional hardness and resistance to abrasion, combined with moderate impact, higher resistance than conventional electrodes (because of the low dilution with the base metal).

Hard facing is used to enhance surface properties of a metallic component, as a specially designed alloy is surface welded to achieve specific wear resistant properties. Surface properties and quality depend upon the selected alloy and welding process. Several welding techniques such as MMAW, OAW, GMAW and SAW can be used for hardfacing. The most important differences among these techniques lie in the welding efficiency, the weld plate dilution and the manufacturing cost of welding consumables. Welding parameters have been found to affect the properties of hardfacing deposits [4, 5]. The weld deposition of hardfacing alloys is commonly employed in industry to increase the service life of components subjected to abrasive wear [6-8]. Slurry erosion is a type of abrasion wear commonly encountered in slurry pump casings and impellers, which decreases their life and requires frequent replacement. To increase in-service operation

time, these impellers and casings are made up of extremely thick cross-sections. This increases the weight of these components, resulting in high operating power requirements and also increases the component production cost. A competitive alternative would be the use of hardfaced material for impellers and casings. Work done by several researchers included the comparison with different hardfacing processes [9-11], wear and corrosion resistance behavior and microstructure features for different alloys [12-15]. It has been observed that the main purpose of hardfacing is to reduce wear and tear by enhancing wear resistance. For this purpose, a composite tubular electrode is developed using pre-determined percentage of chromium carbide filled into the tubular electrode and baked in furnace for a stimulated time period. Due to presence of three factors which affect the performance of hardfaced surface, Taguchi method of orthogonal array testing is applied and welding process is carried out using manual metal arc welding technique and microstructure and hardness of the surface welded is found out.

EXPERIMENTAL STUDIES

During the course of this work, a series of tubular electrodes with different compositions are prepared. The first was the preparation of composite mixture of filler metal powder. The second step was the filling of composite mixture into the tubular electrode.

Table 1: The Percentage Chemical Composition of Ingredients of the Tubular Electrode

C	Mn	Si	Cr	Ni	Mo	Fe
4.8%	1.1%	1.4%	20%	0.5%	1.7%	Balance

The percentage chemical compositions are shown in Table 1. These percentage chemical compositions are considered form literature review [16]. This percentage weight converted into weight, to do so first we need to find out the volume of electrode using diameter and length. The diameter of electrode is 6.3mm and length is 400mm, by using this, the volume of electrode is 12.46 cm^3. The tubular electrode was purchased from ESAB Company.

Then volume fraction of each individual ingredient was found out by dividing percentage weight by density. These volume fractions are added and compared with the volume of electrode to get the weight of each individual ingredient. The Table 2 shows the percentage weight, density and volume fraction of composite mixture and individual weight of each chemical.

Table 2: The Chemicals Used in Preparation of Tubular Electrode and their Weight

Chemicals	% Weight	Density in g/cm^3	Volume Fraction	Weight in grams
C	4.8	2.62	1.832	4.08
Mn	1.1	7.43	0.148	0.934
Si	1.4	2.33	0.601	1.189
Cr	30	7.19	4.172	25.48
Ni	0.5	8.908	0.056	0.425
Mo	1.7	10.22	0.166	1.444
Fe	60.5	7.86	7.672	51.22
Total	**100**			**84.22**

The prepared composite mixture is then filled into the electrode using a funnel, which is then rammed using a steel wire manually and then it is subjected to baking. Once the tubular electrode is filled with composite chromium carbide mixture, it is rammed thoroughly using a steel wire and then baked in furnace for the pre-determined period of time. After baking, the electrode it is allowed to cool in ambient temperature. After it is cooled, it is weighed and practical and theoretical density of the tubular electrode calculated, and it was found out that there existed thirty percent porosity in the tubular electrode.

Digital indicator which is connected to furnace is used to control, read and display the temperature inside the chamber. Temperature inside the furnace can be varied using the control knob present and the control system present will help to control and set different temperatures, which are set with an accuracy of 1°C. It is a low heat input, chromium-carbide based tubular hardfacing electrode. It is very well known that the major ingredients which provide resistance to abrasion are metallic and non-metallic carbides, owing to their very high hardness. As high volume of carbides is packed into the steel tubes, the resultant weld deposit provides excellent abrasion resistance [26]. The thermal expansion coefficient of chromium-carbide (1.1 x 10^{-5}/°C) is almost the same as MS (1.2 x 10^{-5}/°C), which results in lower residual stresses when the chromium carbides are deposited in a matrix of MS [8]. In this investigation, 6.3 mm diameter tubular electrode was used for hardfacing all specimens.The investigation is aimed at improving the properties of MS through hardfacing. The wear-resistant properties of MS are improved through hardfacing by increasing the hardness value from 18 HRC (MS) to 50 HRC (hardfaced component). Thus, by carrying out hardfacing on MS base material, its properties can be made similar to or better than hardened high alloy steels. This would enable hardfaced MS to be used more widely, because hardfaced MS would be very economical compared to hardened high alloy steel. Table 3 shows the chemical composition and mechanical properties of base metal selected which is mild steel.

Table 3: Chemical Composition (%) and Mechanical Properties of Mild Steel

Wt.%						**Hardness**	**Tensile Strength**	**Yield Strength**
C	Mn	Si	S	P	Fe			
0.2	0.9	0.2	0.04	0.03	Balance	18 HRC	485 MPa	275 MPa

A MS plate of 5 mm thickness was taken and a rectangular piece of 85 x 30 x 5 mm was cut out from it. The specimen was checked for its straightness and cleaned properly using emery paper down to +500 grit size and wire brush, before taking it for hardfacing. No prior heat treatment of the specimen was done and the specimen was directly hardfaced after cleaning. The technique adopted for hardfacing electrode is Manual Metal Arc Welding (MMAW) using prepared tubular electrode. This process requires an AC welding machine or DC rectifier based welding machine which is readily available in most of the industries.

DESIGN OF EXPERIMENT

Nine different types of specimens were prepared by depositing nine different hardfacing electrodes on MS. A short arc length (4.8 mm) was maintained to prevent loss of alloying elements and dilution of the hardfacing deposit by the base metal. The purpose of etching is two-fold. Grinding and polishing operations produce a highly deformed, thin layer on the surface which was removed chemically during etching. Secondly, the etchant attacks the surface with preference for those sites with the highest energy, leading to surface relief which allows different crystal orientations, grain boundaries, precipitates, phases and defects to be distinguished in microscopy. The details of the etchant used are given in The hard faced samples were ground with a series of emery paper (up to 2000 grit size) and polished with diamond paste (1-2 microns size). The samples were etched with Marble's reagent. Photomicrographs were taken using optical microscope. The optical microscope is an important tool of the metallurgist from both the scientific and technical standpoints. It is used to determine grain size; size, shape, distribution of various phases and inclusions which have a great effect on the mechanical properties of metals. The microstructure will also reveal the mechanical and thermal treatment of the metal. The aim of metallographic sample preparation is to reveal the true structure of the sample, whether it is metal or any other solid material.

The Rockwell hardness test method as per ASTM E-18 consists of indenting the test material with a diamond cone or hardened steel ball indenter. The prepared specimen was placed on the surface of the Rockwell Hardness tester. A minor load was applied and the gauge was set to zero. The major load of 150 kg was applied by tripping the lever. After 15 seconds, the major load was removed. The specimen was allowed to recover for 15 seconds and then the hardness was read on the dial (C scale) with the minor load still applied. Again on the same specimen on different place the same procedure is carried out and like this four hardness values are calculated on one specimen and mean of the four values is taken as the Rockwell hardness number. The same procedure is carried out for all other specimens and Rockwell hardness number is calculated. An adequate spacing was maintained between multiple indentations. The following levels are considered for each factor. Table 4 shows the three factors and three levels considered for the current experiment.

Table 4: Tubular Electrode Parameters and their Levels

Factor	Name	Units	Level1	Level2	Level3
A	Baking temperature	°C	300	350	400
B	Time of baking	Hours	2	2.5	3
C	Percentage of Cr	%	20	25	30

RESULTS AND DISCUSSIONS

Taguchi Technique

L_9 orthogonal array was chosen to conduct tubular electrode hardfacing experiments. Surface hardness was chosen as response with three replicates. The baking temperature (A), baking time (B), % of Cr (C) were assigned as parameters to the 1st, 2nd, 3rd column of L_9 array, respectively. The L_9 orthogonal array is represented in Table 5. The average (X), standard deviation (σ) and S/N ratios of the surface hardness response were computed and are also shown in Table 5 below.

Table 5: Experimental Data and Hardness Values

Exp No	Main Factors			Observed Response (Roughness)				Average	Standard Deviation	S/N Ratio
	A	B	C	1	2	3	4			
1	300	2	20	40	41	39	41	40.25	0.957	-32.47
2	300	2.5	25	43	42	44	42	42.75	0.957	-32.99
3	300	3	30	43	44	45	46	44.50	1.290	-30.74
4	350	2	30	43	42	44	45	43.50	1.290	-30.55
5	350	2.5	20	47	47	49	48	47.75	0.957	-33.95
6	350	3	25	45	46	44	44	44.75	0.957	-33.39
7	400	2	25	50	49	51	52	50.50	1.290	-31.84
8	400	2.5	30	53	50	51	52	51.50	1.290	-32.01
9	400	3	20	52	49	50	51	50.50	1.290	-31.84

OPTIMIZATION BASED ON MEAN OF MEAN VALUES

The effect of individual parameters on average hardness values is shown in Figure 1. The average of the hardness can be calculated by $(A_i+A_j+A_k)/3$ where I, j and k are the levels of parameters, The range of average responses shown in the Table 2, over the three levels of each experimental factor, is: baking temperature (A), baking time (B), % of Cr (C). It is observed from the graph that the best parameter are A3 (i.e.400°C), B2 (i.e.2.5 hr), C3 (i.e.30% of Cr). From these parameters the highest value of hardness is observed from the Table 5. The surface hardness values increases with the increase in the baking temperature. The surface hardness increases until the moderate baking time is reached and decreases at higher levels of baking time. Also Surface hardness initially decreases till moderate levels of Cr % are reached and it increases at higher levels.

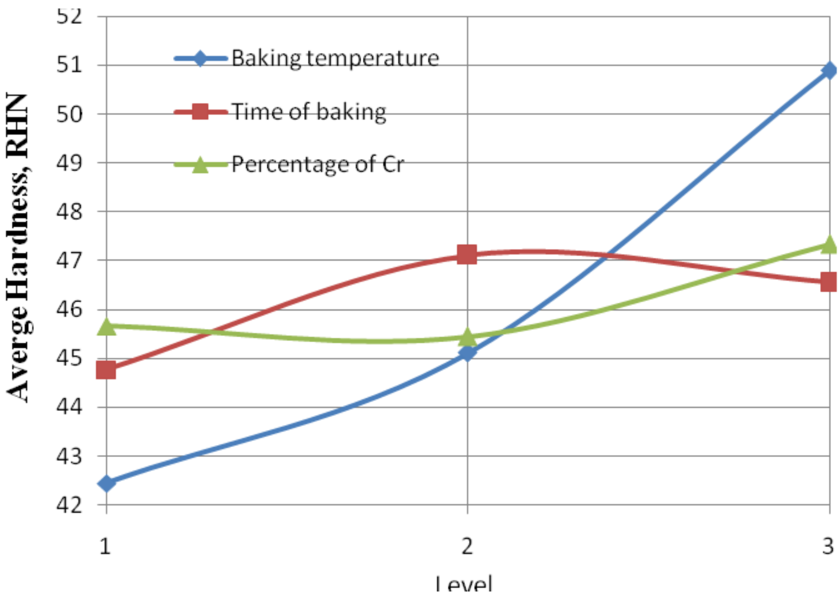

Figure 1: Effect of Individual Parameters on Average Hardness Value of Hardfaced Surface

OPTIMIZATION BASED ON S/N RATIO

The effect of individual parameters on S/N ratio values of hardness of the hard faced surface is plotted in Figure.2.

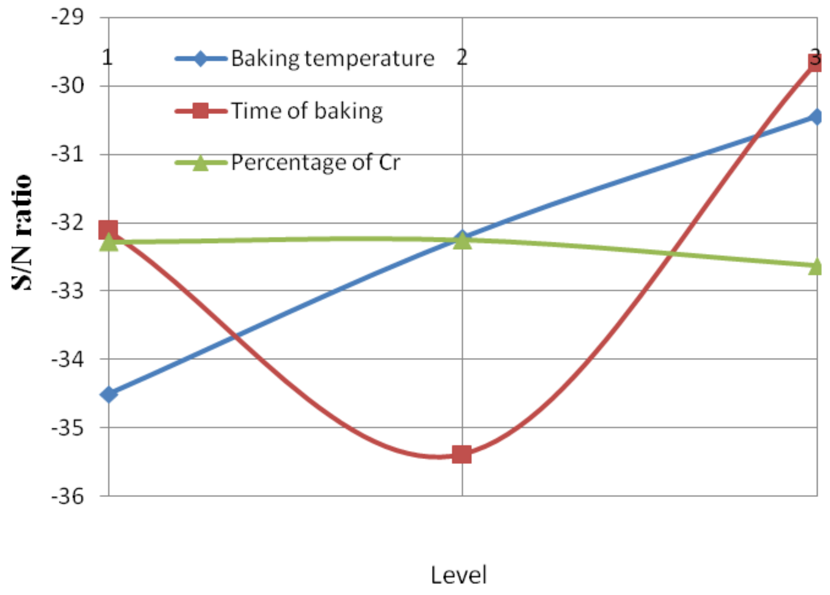

Figure 2: Effect of Individual Parameters on S/N Ratio Values of Hardness on Hardfaced Surface

The S/N ratio of hardness values of the hardfaced surface can be calculated by

$$S/N\ ratio = -10\log\left(\left(\frac{1}{n}\right)\left(\sum\left(\frac{1}{y^2}\right)\right)\right),$$

Where, y is the observed data, n is the number of samples.

The effect of individual parameters on S/N ratio of hardness values of hardfaced surface is shown in Figure 2. The range of S/N ratio over the three levels of each experimental factor, that is: baking temperature (A), baking time (B), % of Cr (C). It is observed from the graph, that the best parameters are A3 (i.e.400°C), B2 (i.e.2.5 hr) and C1 (i.e.20% Cr). From

these parameters the experimental procedure was repeated, and the hardness obtained from these parameters is 54 HRC, which justifies the optimization of parameters of S/N ratio.

ANOVA FOR HARDNESS

Table 6 shows the process parameters (factors) that were chosen for the development of composite tubular electrode. Three levels were specified for each parameter. Below table shows the ANOVA for hardness of hardfaced surface.

Table 6: ANOVA for Hardness

Factors	A	B	C	E	Total
Sum at factor level	96.2185	94.8718	98.2778	97.8845	289.833
	97.9023	98.9715	98.2376	95.3952	
	95.7122	95.9897	98.3176	96.5533	
Sum of squares of differences	7.8881	23.7356	48.8116	9.3099	92.7452
Degrees of freedom	2	2	2	2	8
% Contribution	8.51	28.83	52.63	10.04	100
Optimum level	3	2	1		
	A2	B2	C3		
	350ºC	2.5 hr	30% Cr		

From Table 5 the values of sum at factor level, sum of squares of differences and % contribution are found as shown in Table 6 and it can be seen that the second level of factor (A) give the highest summation (i.e. A2, which is 300°C of baking electrode). The highest summation for factor (B) is at the second level (i.e. B2, which is 2.5 hr of baking of electrode) and the highest summation for factor (C) is at the third level (i.e. C3, which is 30% volume fraction of chromium in composite mixture). These results have proved the success of Taguchi method in the prediction of the optimum parameters for higher hardness. In table it can be seen that the highest summation is at A2 (350°C), B2 (2.5 hr), and C3 (30 % volume fraction). This also proves the success of Taguchi method. From table 6, it was found that the volume fraction of chromium contributes a larger impact on hardness of the composites followed by temperature of baking of electrode then finally time period of baking.

Taguchi’s and S/N ratio methods used to determine the optimal process parameters which minimize the number of experimentations to be conducted to determine the hardness of hardfaced surface were found fruitful. For this purpose, concepts like orthogonal array, S/N ratio and ANOVA were employed. The optimum level of parameters to obtain good hardness of hardfaced surface using tubular electrode are, baking temperature of 350°C and baking duration of 2.5 hours and 30% Cr in composite mixture of tubular electrode. The optical microscope, experimental results and hardfaced surface justify both Taguchi and S/N ratio optimization techniques. Wt. % of Cr has contributed to hardness (52.63%), duration of baking of electrode (28.83%) and baking temperature (8.51 %). From the analysis it was evident that the volume fraction of chromium is a major contributing factor for improving hardness.

CONCLUSIONS

In this work, Taguchi method was applied to determine the optimal process parameters which maximize the hardness of hardfaced surface using composite tubular electrode. For this purpose, concepts like orthogonal array, S/N ratio and ANOVA were employed. The optimum level of process parameters to obtain good mechanical properties for the hardfaced surface are 30% volume fraction of chromium, 300°C of baking and 2.5 hr of baking electrode for maximum hardness. From the analysis, it was evident that the volume fraction of chromium is a major contributing factor (52.6%) for

improving hardness, while other contributing factors are duration of baking of electrode (28.83%) and baking temperature (8.51 %). Taguchi method has proved its success in prediction the optimum parameters to reach the best properties.

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